Effect of Seasonal Changes in Soil Temperature and Moisture on Wood Consumption and Foraging Activity of Formosan Subterranean Termite (Isoptera: Rhinotermitidae)

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ABSTRACT The objective of this study was to determine how seasonal changes affect the foraging activity and wood consumption of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), in New Orleans, LA. There was a significant correlation between wood consumption and air temperature, soil temperature, and soil moisture, but not precipitation or number of rainy days. In the first year of the study, wood consumption was the lowest in December, February, and March. Wood consumption in January was not significantly different from consumption during the rest of the year. There were no seasonal changes in the number of underground monitoring stations occupied by termites. In the second year of the study, wood consumption was lowest from January to March. There was a significant decrease in the number of monitoring stations occupied by termites during the winter. This study determined that *C. formosanus* will remain in monitoring stations and resume feeding during warmer periods of a mild winter if average soil temperatures remain above 15°C. Only prolonged periods of cold weather, with average soil temperatures below 15°C, caused a significant number of termites to abandon underground monitoring stations. Seasonal changes in foraging activity would probably only disrupt baiting programs during severe winters in New Orleans, LA.

KEY WORDS subterranean termite, feeding rates, monitoring station, seasonal trends

Seasonal patterns in the foraging activity of termites have been correlated with both air temperature and precipitation (Haverty et al. 1974, La Fage et al. 1976, Ueckert et al. 1976, Waller and La Fage 1987, Abensperg-Traun 1991, Haagsma and Rust 1995, Rust et al. 1996, Dibog et al. 1998, Haverty et al. 1999, Evans and Gleason 2001, Dawes-Gromadski and Spain 2003, Messenger and Su 2005, Moura et al. 2006). Daily foraging activity of *Coptotermes lacteus* (Froggatt) was correlated with both soil and air temperature (Evans and Gleason 2001). Soil temperature significantly affected the seasonal foraging activity of subterranean termites in New Orleans, LA (Fei and Henderson 2004). In Brazil, soil moisture affected the foraging behavior of two termite species differently. Feeding at baits was negatively correlated with soil moisture for *Coptotermes getroi* (Wasmann) and positively correlated with soil moisture for *Heterotermes longiceps* (Snyder) (Santos et al. 2010). Hence, effects of soil moisture and temperature on subterranean termite foraging activity vary depending on the specific microclimatic requirements of each species.

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Because the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), is a major structural pest, it is important to understand how seasonal patterns influence its foraging behavior. Studies have shown that seasonal changes in the foraging behavior of subterranean termites may influence the efficacy of baiting programs due to the decline of activity during winter (Ripa et al. 2007, Haverty et al. 2010). For example, Haverty et al. (2010) suggest that baiting should be initiated before peak annual wood consumption is reached for *Reticulitermes hesperus* Banks in California to reduce time needed to achieve control.

Although studies have examined the effect of seasonal changes on the foraging activity of *C. formosanus*, the effects of soil moisture and temperature have not been examined. Seasonal changes in feeding rates of *C. formosanus* colonies living in bald cypress, *Taxodium distichum* (L.) Rich., trees in Lake Charles, LA, were studied over a 2-yr period (Delaplane et al. 1991). Feeding rates were highest in the summer and varied positively with daylength and daily maximum ambient air temperature. Feeding rates were significantly correlated with temperature, but not precipitation. Because these trees were submerged in water, termite colonies were confined to the trees and were not able to forage in the soil. Therefore, variability in soil temperature or moisture would have no effect on these colonies. In Armstrong Park, New Orleans, LA, Messenger and Su (2005) found that the foraging activity of *C. formosanus* increased during the summer and declined in the winter and that both wood consumption and percentage of monitoring stations occupied by termites fluctuated seasonally over a 4-yr period. However, it was not determined whether these seasonal differences were significant.

The purpose of this study was to determine whether seasonal changes in temperature and moisture affect the foraging activity and wood consumption of *C. formosanus* in New Orleans. Seasonal changes in the foraging behavior of *C. formosanus* could affect the efficacy of baiting programs for termite control. Wood consumption and foraging activity was monitored in underground stations for 2 yr.

Materials and Methods

Populations of *C. formosanus* have been monitored monthly in City Park in New Orleans, LA, and the surrounding area since 1999, with the exception of September 2005. Underground monitoring stations consist of cylindrical irrigation valve boxes (22.5 by 14.8 cm; NDS, Lindsay, CA) buried in the ground so that the lids are level with the surface of the soil and filled with blocks of wood (spruce [*Picea* sp.]). Every month, 112 monitoring stations in the study area were checked for termite activity, and new wood was added as needed. The total number of monitoring stations in the study area occupied by *C. formosanus* was recorded every month for the duration of the field test.

A field test was conducted from June 2008 to June 2010. In June 2008, 20 test stations were selected from the 112 monitoring stations in locations that included 12 *C. formosanus* colonies. These test stations were selected because they had been consistently occupied by *C. formosanus.* Ten colonies were located in City Park, one colony was located within 1.6 km of the park near the Orleans Canal, and one colony was located within 1.6 km of the park near Bayou St John. At the start of the field test, all wood was removed from the 20 test stations and replaced with 10–15 preweighed wood bundles. In each bundle, seven or eight individual blocks of spruce (7.5 by 3.8 by 0.8 cm) were tied together with plastic ties.

All monitoring and test stations were checked monthly. During summer, test stations were checked every 2 wk. If necessary, additional preweighed bundles of wood were added to stations to replace bundles that had been completely consumed by termites. The bundles were added to prevent termites from consuming all of the wood and abandoning the test stations before monthly checks. The weights of these additional bundles were recorded.

For the 20 test stations, all wood was collected and immediately replaced with new preweighed wood bundles every month. Collected wood was brought back to the laboratory, individual blocks were separated from bundles, and termites were removed from wood. Wood was rinsed and scrubbed with a brush to remove all soil and carton material and then air-dried in the laboratory. After wood had air-dried, weights were taken. Wood consumption for each station was measured by subtracting the weight of wood recovered from each station from the total weight of wood placed in that station during the month. Changes in weight of wood in stations with no termite activity or feeding damage served as a measure of the error in our methods for determining wood consumption and were calculated from 25 collections with no feeding damage, with a mean $\pm$ SE difference of 9.96 $\pm$ 1.4 g, representing <1–2% of weight loss caused by termite feeding activity.

Every month, five soil temperature and soil moisture readings were taken within 0.5 m of each test station. Soil temperature readings were taken using a soil thermometer that reached a depth of 18 cm in the soil (Forestry Suppliers, Jackson, MS). From July 2008 until May 2009, soil moisture readings were taken using the Aquaterr Moisture Meter (Aquaterr Instruments Inc., Costa Mesa, CA) that reached a depth of 20–22 cm in the soil. From May 2009 to June 2010, soil moisture readings were taken using Fieldscout TDR 300 soil moisture meter that reached a depth of 20–22 cm in the soil (Spectrum Technologies, Plainfield, IL). Average monthly soil temperature and moisture readings were calculated for each test station based on five readings per station.

Average monthly air temperatures, total precipitation, and days of recorded precipitation >0.3 cm were obtained for the NOAA station at the Lakefront airport located 6–13 km from the monitoring stations (NOAA 2010). Historic average air temperatures, precipitation, and number of rainy days for New Orleans based on 48 yr of records were obtained from weatherbase website (Weatherbase 2010).

Statistical Analysis. Differences in air temperatures and precipitation for year 1, year 2, and historical averages were compared using a one-way Kruskal–Wallis analysis of variance (ANOVA) because the tests for normality failed. Due to a lack of significance, no multiple comparison tests were performed. Differences in rainy days for year 1, year 2, and historical averages were compared using an ANOVA, and means were separated using Tukey's honestly significant difference (HSD) test. Differences in wood consumption by termites each month and in each station for each year were compared using one-way Kruskal–Wallis ANOVA because the tests for normality failed. Means were separated using Tukey's test with ranked sums. Differences in soil temperatures in year 1 and year 2 were compared using a *t*-test.

In year 1, a multiple linear regression was conducted to determine the effects of average monthly air temperature, total monthly precipitation, and number of rainy days on wood consumption in each of the 20 test stations. Wood consumption data were transformed by the square root to equalize variances and a linear regression was conducted to determine effects of soil temperature on wood consumption. A multiple linear regression also was conducted to determine the effects of average monthly soil temperature, air temperature, and total monthly precipitation on both the number of test stations (20) and monitoring stations (112) occupied by termites.

In year 2, a multiple linear regression was conducted to determine the effects of average monthly air temperature, total monthly precipitation, and number of rainy days on wood consumption in each of the 20 test stations. Wood consumption data were ranked to equalize variances and a multiple linear regression was conducted to determine the effects of soil temperatures and soil moisture on wood consumption. A multiple linear regression was conducted to determine the effects of air temperature, precipitation, and number of rainy days on number of test stations and monitoring stations occupied by termites. Because of multicollinearity between precipitation and soil moisture, a separate multiple linear regression was conducted to determine the effects of average monthly soil temperature and soil moisture on number of test stations and monitoring stations occupied by termites. All analyses were conducted using SigmaPlot 11.0 (Systat Software 2008).

Results

Comparison With Historic Average Temperatures, Precipitation, and Number of Rainy Days. In year 1 (July 2008–June 2009), winter air temperatures (December–February) were slightly higher than historic average temperatures. In year 2 (July 2009–June 2010), air temperatures in January and February were slightly lower than historical average temperatures (Fig. 1A). The maximum temperatures reached 27°C in December 2008 and 26°C in January 2009, but the temperatures only reached 23.8°C in December 2009 and January 2010 and 20.5°C in February (NOAA 2010). However, there was no significant difference in air temperature for year 1, year 2, and the historical average ($H = 0.47$, df = 2, $P = 0.79$).

In year 1, precipitation at the Lakefront NOAA station peaked at 27.7 cm in July and declined to a low of 3.0 cm in June and in year 2, precipitation at the Lakefront NOAA station peaked in December at 52.3 cm and reached a low in November with 2.5 cm (Fig. 1B). There was no significant difference in overall precipitation from year 1, year 2, or the historical average ($H = 3.9$, df = 2, $P = 0.14$).

There was a significant difference in the number of rainy days per month historically compared with year 1 and 2 ($F = 8.5$; df = 2, 35; $P = 0.001$). Both the historical average number of rainy days (9.5 ± 0.7) and the average number of rainy days (7.8 ± 0.9) in year 2 were significantly greater than the average number of rainy days (5.1 ± 0.6) in year 1 ($P < 0.05$; Tukey's HSD test) (Fig. 1C). Differences in soil temperatures in year 1 and year 2 were significantly different ($P = 0.03$; *t*-test).

Year 1. There was a significant correlation between wood consumption in the test stations and soil temperatures (Table 1). Soil moisture data recorded using the Aquaterr Moisture Meter were not included in the analysis due to inconsistencies with the measurements. There was a significant correlation between average wood consumption measured each month and average monthly air temperatures but not of total monthly precipitation or number of rainy days (Table 1).

There were significant differences in monthly wood consumption ($H = 98.3$, df = 11, $P < 0.001$). There was a significant decrease in wood consumption from October to December, a peak in January, and a significant

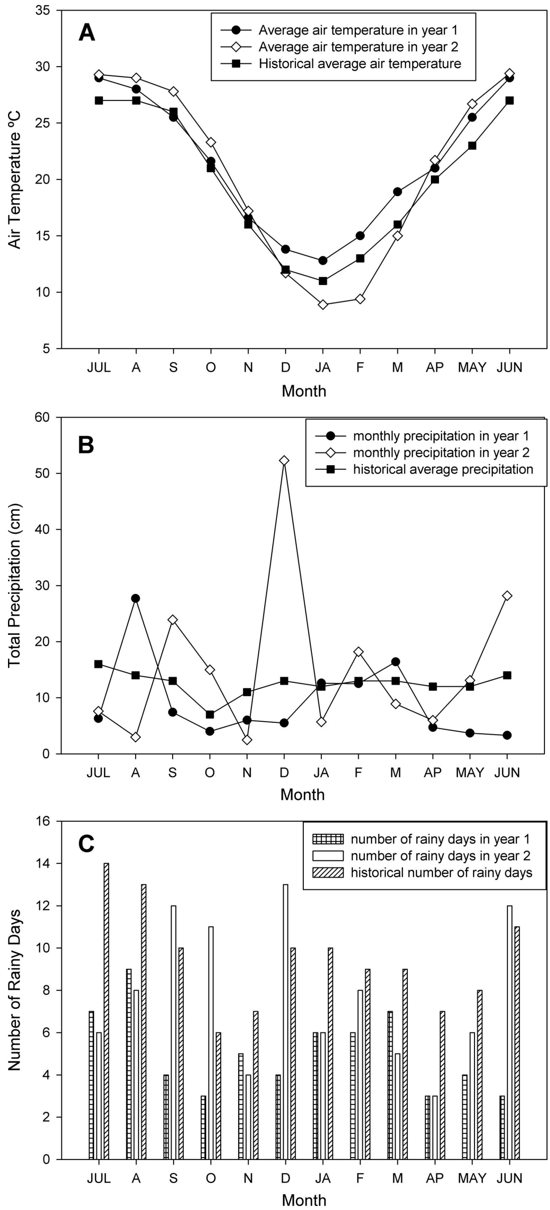

Fig. 1. Air temperatures, precipitation, and number of rainy days measured at the NOAA Lakefront weather station in New Orleans, LA, during year 1 and year 2 compared with historical weather data for New Orleans. (A) Average monthly air temperatures. (B) Total monthly precipitation. (C) Monthly number of rainy days with recorded precipitation >0.3 cm.

Table 1. Linear regression of wood consumption (grams), number of test stations occupied or number of monitoring stations occupied and average monthly soil temperature, air temperature, total monthly precipitation, and number of rainy days in year 1 (July 2008–June 2009)

Variable	Source	*n*	y intercept	Slope	R^2	*P*
Wood consumption[a,b]	Soil temp	240	−0.244	5.9	0.13	<0.001
Multiple regression			−3.572		0.75	
	Air temp	12		4.67		0.002
	Precipitation	12		1.32		0.22
	No. of rainy days	12		−1.87		0.10
No. of test stations occupied (out of 20)						
Multiple regression			19.6		0.31	
	Soil temp	12		−1.27		0.24
	Air temp	12		1.58		0.15
	Precipitation	12		−0.75		0.48
No. of monitoring stations occupied (out of 112)						
Multiple regression			42.4		0.59	
	Soil temp	12		0.54		0.61
	Air temp	12		0.69		0.51
	Precipitation	12		−2.6		0.03

[a] Effect of soil temperature on wood consumption was determined based on measurements taken from 20 test stations each month.
[b] Data on weight loss of wood were transformed by the square root before analysis to equalize variances.

increase in wood consumption from March to April (Fig. 2). Thus, wood consumption decreased significantly in the winter months.

There was no correlation between soil temperatures and the number of test stations or monitoring stations occupied by termites (Table 1). There was a significant correlation between the number of monitoring stations occupied by termites and the total monthly precipitation but not the average monthly air temperature (Table 1). The number of test stations and monitoring stations occupied by termites did not change seasonally (Fig. 3).

There were significant differences in wood consumption per station ($H = 70.49$, df = 19, $P < 0.001$). Average wood consumption at Station P was >3 times greater than average wood consumption at station A ($P < 0.05$; Tukey's test with ranked sums) (Fig. 4A).

Year 2. There was a significant correlation between wood consumption and both soil temperature and soil moisture (Table 2). There was also a significant correlation between wood consumption and monthly air temperatures but not precipitation or number of rainy days (Table 2).

There were significant differences in wood consumption for each month ($H = 142.19$, df = 11, $P < 0.001$). Wood consumption was highest in June and lowest in March (Fig. 5). Wood consumption was significantly lower in winter than during the rest of the year. In fall and spring, average wood consumption increased with increasing soil moisture (Fig. 6).

The number of test stations and monitoring stations occupied by termites were significantly correlated with soil and air temperatures but not soil moisture, precipitation, or number of rainy days (Table 2). There was a decline in the number of both test stations and monitoring stations occupied by termites during winter (Fig. 7).

There were significant differences in wood consumption per station ($H = 59.05$, df = 19, $P < 0.001$).

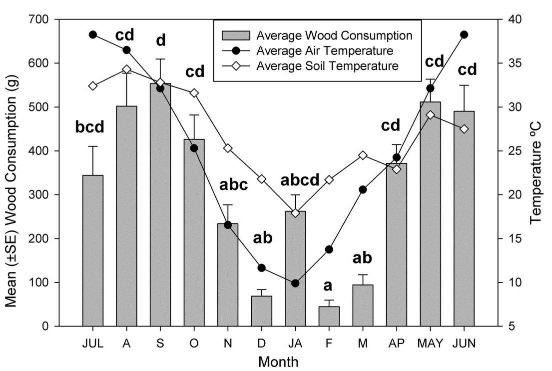

Fig. 2. Mean ± SE wood consumption (grams) per station for each month in year 1 (8 July–9 June). Bars with the same letters are not significantly different ($P > 0.05$; Tukey's test with ranked sums). Lines represent average monthly temperatures in year 1 for soil (white diamond) and air (black circle).

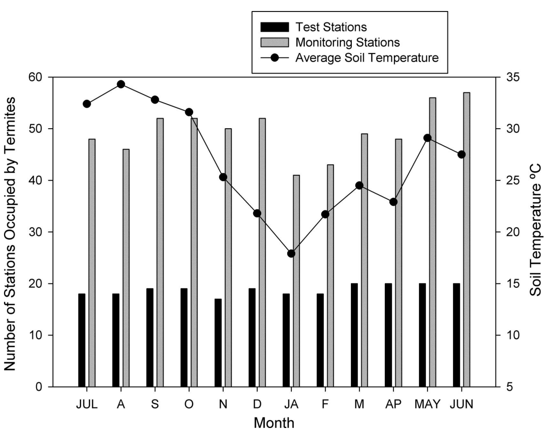

Fig. 3. Number of test stations (out of 20) and number of monitoring stations (out of 112) occupied by termites in year 1 (8 July–9 June). Line represents average monthly soil temperatures in year 1.

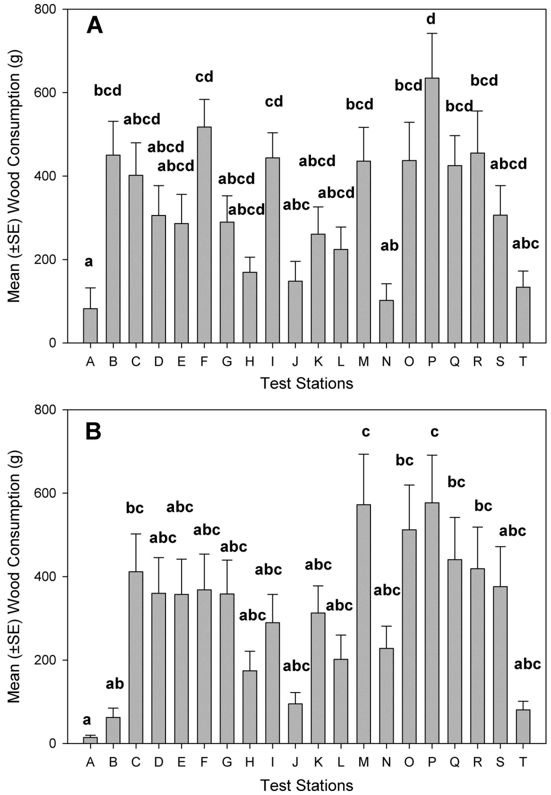

Fig. 4. Mean ± SE wood consumption (grams) per station in year 1 (A) and year 2 (B). Bars with the same letters are not significantly different ($P > 0.05$; Tukey's test with ranked sums).

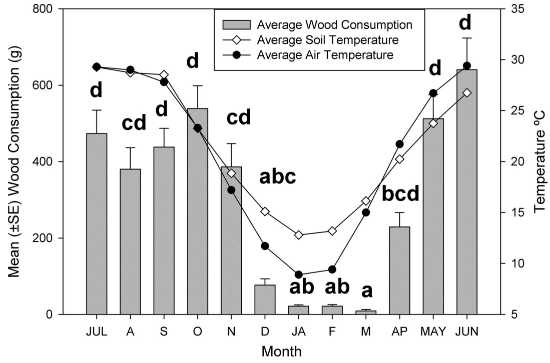

Fig. 5. Mean ± SE wood consumption (grams) per station for each month in year 2 (9 July–10 June). Bars with the same letters are not significantly different ($P > 0.05$; Tukey's test with ranked sum). Lines represent average monthly temperatures in year 2 for soil (white diamond) and air (black circle).

Average wood consumption of stations P and M was >500 g, whereas average wood consumption of station A was only 14.5 g ($P < 0.05$; Tukey's test with ranked sums) (Fig. 4B).

Discussion

There are significant seasonal changes in the feeding rates of *C. formosanus* in New Orleans. In both years of the study, termites consumed significantly less wood during the winter. Although the feeding rate was significantly lower in December, February, and March in year 1 compared with August through October and

Table 2. Linear regression of wood consumption (grams), number of test stations occupied or the number of monitoring stations occupied and average monthly soil temperature, soil moisture, air temperature, total monthly precipitation, and number of rainy days in year 2 (July 2009–June 2010)

Variable	Source	*n*	y intercept	Slope	R^2	*P*
Wood consumption[a,b]						
Multiple regression			−91.14		0.41	
	Soil temp	240		12.78		<0.001
	Soil moisture	240		3.76		<0.001
Multiple regression			−267.91		0.79	
Air temp		12	4.50	0.002		
	Precipitation	12	−0.38	0.72		
	No. of rainy days	12	0.72	0.49		
No. of test stations occupied (out of 20)						
Multiple regression			5.51		0.645	
	Soil temp	12		3.8		0.004
	Soil moisture	12		−0.08		0.93
Multiple regression			8.68		0.78	
Air temp		12		5.10		0.006
	Precipitation	12		1.12		0.29
No. of rainy days		12		−1.43		0.19
No. of monitoring stations occupied (out of 112)						
Multiple regression			9.88		0.50	
	Soil temp	12		2.85		0.02
	Soil moisture	12		−0.10		0.93
Multiple regression			24.25		0.79	
	Air temp	12		5.10		<0.001
	Precipitation	12		1.13		0.29
	No. of rainy days	12		−2.1		0.07

[a] Effect of soil temp and moisture on wood consumption on were determined based on measurements taken from 20 test stations each month.
[b] Data on wood consumption were ranked before analysis to equalize variances.

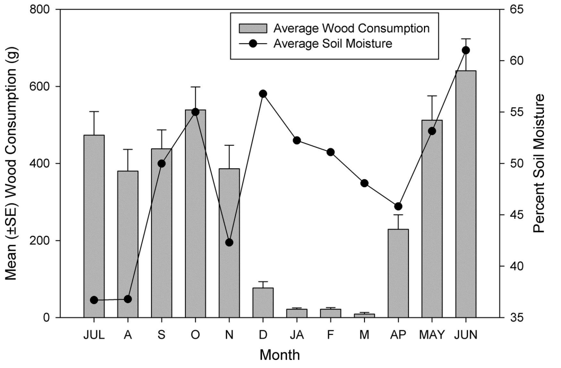

Fig. 6. Mean ± SE wood consumption (grams) per station for each month in year 2 (9 July–10 June). Bars with the same letters are not significantly different ($P > 0.05$; Tukey's test with ranked sums). Line represents average monthly soil moisture in year 2.

May and June, there was an increase in feeding in January 2009. Feeding rates in January 2009 were not statistically different from feeding rates during the rest of the year. The increased feeding recorded for January 2009 may have occurred during a brief period of warmer weather that occurred from mid December to mid-January when feeding was measured. Maximum temperatures reached 27°C in December 2008 and 26°C in January 2009 (NOAA 2010). In contrast, feeding rates were the lowest from January to March in year 2.

There were no significant changes in the number of monitoring stations occupied by termites during the first year of our study, but there was a significant drop in termite occupancy of stations during the winter in year 2. The critical thermal minima for *C. formosanus* have been measured to range from 7.2 to 9.0°C, depending on the season (Hu and Appel 2004). In year 1, soil temperatures near monitoring stations never dropped low enough for termites to abandon stations. The lowest soil temperature recorded was 15.2°C, and the lowest average soil temperature was 17.5°C in January 2009. In year 2, the lowest soil temperature

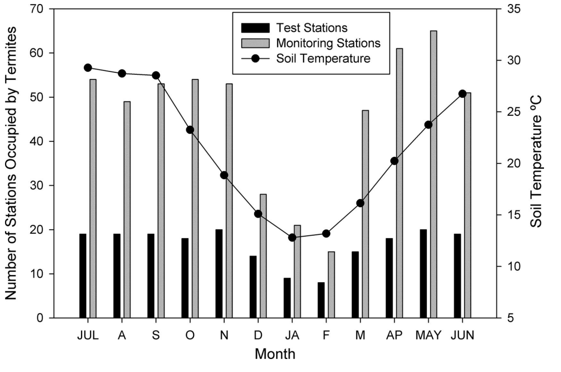

Fig. 7. Number of test stations (out of 20) and number of monitoring stations (out of 112) occupied by termites in year 2 (9 July–10 June). Line represents average monthly soil temperatures in year 2.

recorded was 9.4°C and the lowest average soil temperature was 12.8°C in January 2010. Because soil temperatures in year 2 were significantly lower than in year 1, termites were more likely to abandon stations during the winter during year 2.

Increases in soil moisture were significantly correlated with increases in wood consumption in year 2. However, in the winter, soil moisture increased, whereas feeding rates decreased. In a 2-yr study with the termite *Gnathamitermes tubiformans* (Buckley), both temperature and moisture affected the number of termites foraging in the soil. In a year of above-normal precipitation, temperature was the most important factor affecting the number of foraging termites, whereas during a year of below-normal precipitation, soil moisture was the most important factor (Ueckert et al. 1976). In our study, both soil temperatures and soil moisture increased in spring 2010 in conjunction with increased wood consumption. In the fall of year 2, soil temperatures gradually decreased, whereas soil moisture and wood consumption increased. Soil moisture may have been a significant factor in the increased feeding rates of termites in monitoring stations during fall of year 2.

Feeding rates at individual stations were highly variable. Differences in feeding rates at individual stations could be due to differences in colony size, foraging range, number of alternative food sources, or other factors affecting the station such as human disturbance or temporary flooding. Station A had the lowest feeding rate because the station was only occupied for 14 of the 24 mo of the field test. Station A was abandoned by termites for several months due to human disturbance. This station was probably abandoned by termites more frequently than the other test stations because this station was located in an area that was more accessible to the public that resulted in greater tampering. Station P had the highest feeding rate and was occupied by termites in all 24 mo of the field test. This station has been very active with termites for several years. Although the population sizes of the colonies are unknown, foraging ranges have been delineated using mark–release–recapture studies. Both mark–release-recapture studies and aggression assays have determined that termites from Station P are not connected to any of the nearby stations and seem to be surrounded by other *C. formosanus* colonies (Cornelius et al. 2007, Cornelius 2008). Consumption at this station may be very high because the foraging range of this colony is limited due to intense competition from neighboring colonies.

Although results of this study were consistent with other studies that showed a seasonal fluctuation in foraging activity of *C. formosanus* in Louisiana (Delaplane et al. 1991, Messenger and Su 2005), this study determined that *C. formosanus* will remain in monitoring stations and resume feeding during warmer periods of a mild winter if average soil temperatures remain above 15°C. Only prolonged periods with average soil temperatures below 15°C caused a significant number of termites to abandon underground monitoring stations. Long-term monitoring of foraging activity of *C. formosanus* in City Park also has indicated that termites frequently remain active in underground stations throughout the winter (unpublished data). The efficacy of baiting programs could be affected by seasonal changes in termite foraging activity (Ripa et al. 2007; Haverty et al. 2010). Although feeding rates of *C. formosanus* decline significantly in the winter, termites would probably only abandon bait stations during severe winters where average soil temperatures dropped below 15°C in New Orleans.

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